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THE EFFECTIVENESS OF HEAD RESTRAINTS: AN ANALYSIS OF TEXAS DATA

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FINAL REPORT

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16. Abstract

The primary objective of the report was to determine the injury reducing effectiveness of head restraints in rear impact collisions. Three categories of injuries were analyzed from records on the 1972 Texas accident data set. Multi-dimensional contingency table analysis was used to control for the confounding effects of four variables (vehicle damage severity, driver age, driver sex, and vehicle size). In addition, side impact collisions served as a control group to remove any biases in the raw data. The study found significant effectiveness rates in all three categroies of injuries after controlling for the presence of confounding effects.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

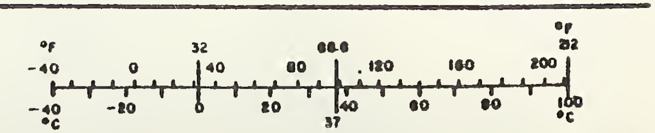

TABLE OF CONTENTS

1

INTRODUCTION

1.1 Background

This report is the first in a series of reports that provide statistical analyses concerning the effectiveness of Federal Motor Vehicle Safety Standard (FMVSS) 202 (Head Restraints). This work was conducted under contract DTNH22-80-C-06017, by Opportunity Systems Incorporated.

There are two primary methods for complying with FMVSS 202. A separate head restraint, which may be adjustable, is attached to the back of the seat. The alternative method is for the head restraint to be an integral part of the seat back. FMVSS 202 went into effect on January 1, 1969. Most automobile manufacturers had complied with the standard by the middle of model year 1969. Head restraints were installed in some cars as early as the 1967 model year.

In complying with FMVSS 202, the head restraint must meet the requirements of either a dynamic or static test.

The dynamic test involves measuring the angular displacement of a manikin's head. The static test measures the rearward displacement of a test dummy head under application of a maximum two hundred pound load. If the manufacturer elects to use the static test, the head restraint must also meet minimum height and width requirements.

1.2 Objective

The primary objective of this report is to determine the injury reducing effectiveness of head restraints in rear impact collisions. The analysis will describe the interactions among control variables, head restraints, and injury reduction. Furthermore, injury rates will be adjusted in order to control for confounding effects.

1.3 Scope

The analysis was done by extracting data elements from records on the 1972 Texas accident data set. These records contain information detailing the location of impact as well as other factors that are associated with driver injury. Statistical models for estimating head restraint effectiveness were developed using the following variables: Injury Severity, Head Restraint Availability, Vehicle Damage Severity, Driver Age, Driver Sex, and Vehicle Size. The analysis was limited to drivers of passenger cars of the model years 1965-72 in order to avoid biases due to the inclusion of old cars.

1.4 Approach

The following approaches were used:

(1) The evaluation of head restraint effectiveness was based on a multi-dimensional contingency table analysis of rear end collision accidents. The records of these accidents were extracted from the 1972 Texas Driver-Oriented accident tape.

(2) The evaluation was based on a comparative analysis of rear and side impact collisions on the 1972 Texas Driver-Oriented accident tape.

1.5 Preparation Of Data For Analysis

Opportunity Systems, Inc. obtained a copy of the Government's Texas 1972 Driver-Oriented accident tape, which was an edited version of the original tape. The editing was performed under contract DOT-HS-8-02014. The tape contains 432,997 accident records. Each accident record is trailed by one or more driver records of 40 characters.

Section 1.5 outlined the criteria for the population that is involved in this analysis. First, the vehicles involved had to be 1965-1972 passenger cars where the type of vehicle and model year were such that an unquestioned determination of head restraint usage (see Appendix B) could be determined. There were 1,746 cases that did not have this information. Second, the collision had to involve a rear

impact. Including the 59,145 cases that did not have information about the type of accident, 347,642 cases were eliminated because of this criterion. Finally, approximately 2,000 records were excluded because of missing data on a control variable. These procedures yielded a file of 63,645 drivers involved in rear impacts. A breakdown of these cases may be found in Appendix A.

1.6 Data Characteristics

Each extracted case includes information on the following six factors:

- Injury (K + A, B, C, O, or "No Information")*
- Head Restraints (Yes, No)**
- TAD Severity (1-2, 3-4, 5-7)
- Driver Age (1-29, 30-49, 50+)
- Driver Sex
- Vehicle Size (Small, Large)***

1.7 Limitations of the Study

The analysis will be confined to drivers who were involved in rearend collisions. Prior research with the Texas accident data set has revealed a severe bias

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*In Texas, "no information" on driver injury means that the driver was not injured.

**Based on a look-up table by make, model and model year. The look-up table is based on National Crash Severity Study tabulations and can be found in Appendix B.

***Small cars are defined as 3500 lbs. and under; large cars are 3502 lbs. and over.

towards injured front seat passengers. Specifically, there is an underrepresentation of front seat passengers who were not injured in an accident. In most instances, information regarding these passengers was not recorded.

Since police-reported accident data were used, it was not possible to isolate "whiplash" from other rear-impact injuries. Also, "whiplash" symptoms often do not appear until sometime after the accident. In those cases, they would not be mentioned in a police report which is prepared at the accident scene.

In the course of complying with FMVSS 202, some manufacturers did not begin installing head restraints until the middle of their production year. Hence, there are some make-model-year cars in which only a portion of the cars have factory-installed head restraints. These make-model-year cars were excluded from the analysis, (See Appendix B). Finally, no attempt was made in this report to analyze differences between vehicles with integral head restraints and vehicles with adjustable head restraints. The differences will be investigated in a subsequent study.

1.8 Outline of the Report

Section 2 presents the effectiveness findings and the confidence bounds for each of the two analytic approaches.

Section 3 of this report describes the multi-dimensional contingency table analyses of rear impact collision data. This section includes the procedures used in preparing the data for

analyses; estimates of the effectiveness of head restraints for three categories of injuries; and the confidence limits for the effectiveness estimates.

Section 4 presents the calculation of head restraint effectiveness based on the reduction of rear impact injury risk relative to side impact injury risk.

2

FINDINGS AND CONCLUSIONS

2.1 Simple tabulation of rear impact collision data.

	Pre-Standard	Post-Standard	Observed Reduction for Post-Standard (%)
N of crashes	26193	37452	
Per cent of drivers injured	8.04	5.88	26.9
Per cent of drivers with K, A or B injury	1.57	1.11	29.3
Per cent of drivers with K or A injury	0.36	0.23	36.1

2.2 Effectiveness of Standard 202 based on multi-dimensional contingency table analysis of rear impact collisions

Injury rates were adjusted for differences in driver age, sex, TAD severity and vehicle weight.

Type of injury	Effectiveness of Std. 202(%)	Confidence Bounds(%)* Lower	Upper
Any injury	26.3	21.9	30.4
K, A or B injury	27.2	16.3	36.1
K or A injury	34.9	16.7	48.5

*one-sided $\alpha = .05$

2.3 Effectiveness of Standard 202 based on comparison of rear and side impact injury rate reductions

Type of Injury	Observed Injury in Rear Impacts (%) (R)	Reduction in Side Impacts (%) (S)	Effectiveness* of Standard 202(%) (E)	Confidence Bounds (%)** Lower	Upper
Any injury	26.3	10.3	18.5	13.5	22.8
K, A or B injury	29.3	15.2	16.6	5.5	25.8
K or A injury	36.1	16.0	23.9	- 0.2	40.7

$$*E = 1 - \frac{1-R}{1-S}$$

NOTE: Tabulated values of R and S are rounded. Values of E are calculated from unrounded values of R and S. The exact numbers are shown in Table 7.

**One-sided $\alpha = .05$

3

MULTI-DIMENSIONAL CONTINGENCY TABLE ANALYSIS OF REAR IMPACT CRASHES

3.1 Overview

The objective of this section is to determine the reduction of injury risk in rear impacts that can be attributed to head restraints. Section 2.1 showed that the observed driver injury rate in 1972 Texas rear impacts was 27 percent lower in cars with head restraints than in cars without head restraints. But not all of this observed difference is necessarily attributable to head restraints. It is possible that the post-Standard cars had lower injury rates, to some extent, because they were involved in less severe accidents.

Multi-dimensional contingency table analysis has been used for several years to isolate the portion of the injury reduction actually due to a standard from the portion merely due to differences in the characteristics of accidents involving pre-standard and post-standard cars. The technique was used in the evaluation of energy-absorbing steering

columns (DOT HS-805 705, pp.156-183), seat belts (DOT HS-801 833), side door beams (DOT HS-805 661) and other safety standards.

The technique consists of selecting a list of potential control variables: confounding factors which are suspected of having a strong relationship with injury risk and a different distribution for pre and post-standard cars. For example, TAD severity is highly correlated with injury risk. Older cars have, on the average, more severe TAD ratings. Thus, pre-standard cars will have higher injury risk, regardless of whether head restraints are effective.

The control variables that seem to be important and are available in the Texas data are TAD severity, driver age group, driver sex and vehicle weight group. Along with Standard 202 compliance and injury severity, they yield a six dimensional table. Multi-dimensional contingency table analysis (BMDP3F) provides a parsimonious list of interactions between the six variables that accurately predicts the cell entries in the six way table. (These predicted cell entries are more robust than the actual observed entries in the six way table.)

Finally, the table of predicted cell entries is used to estimate the effectiveness of head restraints: first, the four way marginals, for the four control variables, are adjusted to be identical for the pre and post standard populations. At this point, the two populations have identical

distributions in the control variables. Then, the overall marginals for injured and uninjured drivers are computed for the pre and post standard populations. The difference in the marginal injury rates is no longer biased by any of the four confounding factors and is assumed, in this section, to be the injury reduction actually due to head restraints.

The fictitious example shown below illustrates the procedure of "adjusting the marginals" in the simple case when there is only one control variable (speed).

3.2 Construction of Working File for FMVSS 202 Evaluation

The initial procedure in conducting the analysis is to obtain a series of six-way tables. The first table is a six-way table for all categories of each variable. The six variables in the analysis have the following categories:

- Injury (K+A, B, C, O or "No Information")
- Head Restraints (Yes, No)
- TAD Severity (1-2, 3-4, 5-7)
- Driver Age (1-29, 30-49, 50+)
- Driver Sex (M, F)
- Vehicle Size (0-3500 lbs., 3500+ lbs.)

As previously mentioned, "no information" means that the driver was not injured. Also, head restraint usage (Yes, No) was determined through the utilization of the look-up table found in Appendix B. The initial six-way table of all variables by all categories has 288 cells and is reproduced in Appendix C.

FICTITIOUS EXAMPLE SHOWING TECHNIQUE OF

ADJUSTING THE MARGINALS TO EVALUATE "FMVSS 800"

(a) Unadjusted (raw) data

	Pre-FMVSS 800 cars			FMVSS 800 cars		
	Speed < 20	Speed ≥ 20		Speed < 20	Speed ≥ 20	
AIS ≥2	100 25%	300 50%	400 40%	240 15%	140 35%	380 19%
AIS ≤2	300 75%	300 50%	300 60%	1360 85%	260 65%	1620 81%
	400	600		1600	400	

$$\text{Injury reduction before adjustment} = \frac{.4 - .19}{.4} = 53\%$$

(b) Adjusted data

	Pre-FMVSS 800			Post-FMVSS 800		
	Speed < 20	Speed ≥ 20		Speed < 20	Speed ≥ 20	
AIS ≥ 2	500 25%	500 50%	1000 33%	300 15%	350 35%	650 22%
AIS < 2	1500 75%	500 50%	2000 67%	1700 85%	650 65%	2350 78%
	2000	1000		2000	1000	

$$\text{Injury reduction after adjustment} = \frac{.333 - .216}{.333} = 35\%$$

Multi-dimensional contingency table analysis is used to control for the confounding effects of the four variables (TAD Severity, Driver Age, Driver Sex and Vehicle Size). This technique requires the construction of models in order to generate expected frequencies. A second set of 3 six-way tables is obtained in which all variables are categorized as above, except for Injury. Injury is collapsed to a dichotomy, as follows:

(1) Injury collapsed to 2 categories: K+A, all others
(2) Injury collapsed to 2 categories: K+A+B, all others
(3) Injury collapsed to 2 categories: K+A+B+C, all others.

The frequencies from this table will be used in constructing the models for each of the three injury categories.

3.3 Calculation of Effectiveness

The first step in testing the effectiveness of FMVSS 202 is to conduct a basic tabulation for the three categories of injury by head restraint installation (Pre-Standard and Post-Standard). These tabulations and unadjusted injury reduction rates can be found in Table 1.

Table 1 reveals the prominent role that head restraint usage played in reducing injuries for all three categories of injury. The next step is to control for the confounding effects of the remaining four variables (TAD Severity, Age,

TABLE 1

PRE AND POST-STANDARD INJURY RATES FOR DRIVERS IN REAR IMPACTS

K+A INJURIES

	K+A	ALL OTHERS	
Pre	95	26098	26193
Post	85	37367	37452
	180	63465	63645

K+A+B INJURIES

	K+A+B	ALL OTHERS	
Pre	411	25782	26193
Post	415	37037	37452
	826	62819	63645

ALL INJURIES

	K+A+B+C	ALL OTHERS	
Pre	2105	24088	26193
Post	2201	35251	3745[illegible]
	4306	59339	6364[illegible]

CALCULATION OF OBSERVED INJURY REDUCTION

1 - (85/37452)(95/26193) =

1 - (.0023)/(.0036) =

1 - .639 = 36.1% reduction for post-standard

1 - (415/37452)/(411/26193) =

1 - (.0111)/(.0157) =

1 - .707 = 29.3% reduction for post-standard

1 - (2201/37452)/(2105/26193) =

1 - (.0588)/(.0804) =

1 - .731 = 26.9% reduction for post-standard

TABLE 2

SUMMARY OF SIGNIFICANT THREE-WAY INTERACTIONS

I = Injury
H = Head Restraint
T = TAD Severity
A = Age
S = Sex
V = Vehicle Size

Type of Injury

	K + A, All Other			K + A + B, All Other			K + A + B + C, All Other		
	df	X^2	p	df	X^2	p	df	X^2	p
IHT									
IHA									
IHS									
IHV				1	3.95	.047			
ITA									
ITS	2	6.18	.0455	2	7.31	.0259	2	6.52	.0384
ITV									
IAS	2	8.97	.0113						
IAV									
ISV									
HTA									
HTS									
HTV	2	13.13	.0014	2	13.94	.0009	2	13.63	.0011
HAS	2	41.13	.0000	2	41.34	.0000	2	38.48	.0000
HAV	2	417.45	.0000	2	416.36	.0000	2	414.77	.0000
HSV	1	27.87	.0000	1	28.05	.0000	1	27.52	.0000
TAS									
TAV	4	9.95	.0413	4	10.53	.0324	4	10.11	.0387
TSV									
ASV	2	8.78	.0124	2	8.43	.0148	2	7.46	.024

Sex, Vehicle Size.) The first procedure in this step is to calculate the interaction terms among the six variables.

The initial runs of BMD3PF, which may be found in Appendix D, verified that there were no significant four-way or higher interactions. Subsequent runs that tested for all possible three-way interactions can be found in Appendix E and are summarized in Table 2. These three-way interactions reveal only a borderline significant interaction between injury, head restraint usage, and vehicle size for the injury category of K+A+B, all others. The majority of significant three-way interactions are with head restraint usage and the remaining four variables. In other words, head restraints are about equally effective for young and old drivers, men and women, low and higher speed crashes and light and heavy cars. Finally, selected two-way interactions are tested; runs of these tests may be found in Appendix F.

The expected cell values are derived from a parsimonious model that has a good "fit" (i.e., $p > .05$). In other words, a model is constructed that includes only the important interactions between all variables and therefore offers a good prediction of the observed cell entries. It should be noted that the procedure requires inclusion of the two-way interaction between injury and head restraint in all models regardless of

significance. The models eventually selected are presented in Table 3. The BMDP runs which led to the selection of these models may be found in Appendix F.

TABLE 3

Models Selected For Best Fit

I = Injury
H = Head Restraint
T = TAD Severity
A = Age
S = Sex
V = Vehicle Size

<u>K + A</u>

HTV, HAS, HAV, HSV, ASV, IT, TS, IH

df = 108 X^2 = 128.8
p = .082

<u>K + A + B</u>

ITS, HTV, HAS, HAV, HSV, ASV, IH, IV, IA

df = 102 X^2 = 111.7
p = .242

<u>K + A + B + C</u>

ITS, HTV, HAS, HAV, HSV, TAV, ASV, IH, IA, IV

df = 94 X^2 = 114.7
p = .071

The cells that categorize injured drivers (K+A, K+A+B, K+A+B+C) have small frequency counts when compared with the uninjured drivers; because of this, the potential for large sampling error exists when the marginals are adjusted on the control variables. The risk of having small cell counts that are weighted heavily can be reduced by "smoothing" the cell counts via multi-dimensional contingency table analysis

(Charles J. Kahane, <u>An Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies</u>, DOT-HS-805-705, p. 173). The adjusted injury rates can then be calculated using "expected" cell values.

The "expected" cell entries for head restraint usage by injury by each control variable were generated from the models selected. The tables of expected cell values can be found in Appendix G. By using the expected cell values the confounding effects of the control variables can be eliminated by adjusting the marginals of the pre and post Standard populations to have the same distribution on the control variables (Ibid, p. 175).

Let N_{ihtasv} be the cell entries <u>predicted</u> by the models shown in Table 2. Then $N_{11} = \sum_{t=1}^{3} \sum_{a=1}^{3} \sum_{s=1}^{2} \sum_{v=1}^{2} \left(\frac{N_{11\,tasv}}{N_{.1\,tasv}} N_{..tasv}\right)$

is a prediction of the number of rear impact injuries that <u>would have</u> occurred if <u>none</u> of the cars had been equipped with head restraints. Similarly, $N_{12} = \sum_{t=1}^{3} \sum_{a=1}^{3} \sum_{s=1}^{2} \sum_{v=1}^{2} \left(\frac{N_{12\,tasv}}{N_{.2\,tasv}} N_{..tasv}\right)$

is a prediction of the number of injuries that would have occurred if all of the cars had been equipped with head restraints. The <u>effectiveness</u> of head restraints, after <u>adjusting</u> the pre-standard and post-standard populations to have identical distributions on the 4 control variables, is

$$E = \frac{N_{11} - N_{12}}{N_{11}}$$

TABLE 4

ADJUSTED PRE AND POST-STANDARD INJURY RATES
FOR DRIVERS IN REAR IMPACTS

(After controlling for age, sex, TAD and vehicle weight differences)

N_{11}	N_{21}
N_{12}	N_{22}

	K+A	ALL OTHERS			K+A+B	ALL OTHERS			K+A+B+C	ALL OTHERS	
Pre	225.67	63419.33	63645	Pre	981.67	62663.33	63645	Pre	5093.44	58551.56	63645
Post	146.85	63498.15	63645	Post	714.75	62930.25	63645	Post	3754.76	59890.24	63645

Calculation of Standard 202 Effectiveness

	1 - 146.85/225.67		1 - 714.75/981.67		1 - 3754.76/5093.44
=	1 - .651	=	1 - .728	=	1 - .737
=	34.9% reduction due to Standard 202	=	27.2% reduction due to to Standard 202	=	26.3% reduction due to to Standard 202
	(as compared to 36.1% injury reduction observed in the Table 1 raw data)		(as compared to 29.3% injury reduction observed in the Table 1 raw data)		(as compared to 26.9% injury reduction observed in the Table 1 raw data)

The cells in Table 4, which are N_{11} , N_{12} and (similarly calculated) N_{21} and N_{22} , yield adjusted injury rates which can be compared with the unadjusted injury rates from Table 1.

3.4 Derivation of Confidence Bounds

The sample is divided into systematic random subfiles of equal size for purposes of constructing confidence bounds for the adjusted effectiveness rates. Five subfiles are used for the K+A injury calculation because of the relatively small number of injuries in this category. Ten subfiles are used with the other injury criteria. The adjusted injury frequencies, N_{11} and N_{12} , are calculated within each subfile using exactly the same models that were developed in the previous subsection. Table 5 shows the number of injuries, N_{11} and N_{12} , in each subfile, predicted by the models that (Ibid, pp 204-205). Note that, when there are 10 subfiles, we would expect the predicted number of injuries in each subfile to be one tenth the numbers shown in Table 4. In fact, the variation from subfile to subfile is used to calculate the sampling error of the numbers in Table 4.

TABLE 5

NUMBER OF INJURIES,
BY SUBFILE AND STANDARD 202 COMPLIANCE,
USING THE MODEL DEVELOPED FOR THE ENTIRE FILE

	K + A		K + A + B		K + A + B + C	
Subfile Number:	Pre	Post	Pre	Post	Pre	Post
	X_i	Y_i	X_i	Y_i	X_i	Y_i
1	37.59	34.82	117.62	77.77	535.84	378.53
2	51.71	23.58	95.64	86.12	507.53	396.10
3	40.12	27.23	98.36	85.81	543.07	390.94
4	57.52	32.62	81.74	60.00	442.58	379.07
5	38.99	28.83	85.74	64.20	458.76	391.17
6			89.19	83.76	519.96	364.18
7			109.77	74.71	537.47	362.71
8			115.63	71.25	478.53	417.29
9			112.39	58.67	551.55	346.63
10			71.93	53.19	523.16	331.26

NOTE: Xi is N_{11} for the ith subfile
Yi is N_{12} for the ith subfile

The numbers of injuries in Table 5 are utilized in the following formulas to calculate non-symmetric confidence bounds (one-sided α = .05). The derivation of these formulas can be found on pp. 191-192 of a U.S. Department of Transportation report, entitled "An Evaluation of Federal Motor Vehicle Safety Standards for Passenger Car Steering Assemblies."

(1) n = number of subfiles used

(2) $$X = \sum_{1}^{n} X_i$$

(3) $$Y = \sum_{1}^{n} Y_i$$

(4) $$S_X = \left(\frac{n \sum_{i}^{n} X_i^2 - X^2}{n - 1}\right)^{\frac{1}{2}} =$$

(5) $$S_Y = \left(\frac{n \sum_{1}^{n} Y_i^2 - Y^2}{n - 1}\right)^{\frac{1}{2}} =$$

(6) The <u>effectiveness</u>

$$E = (1 - \frac{Y}{X})\%$$

(7) A lower confidence bound for E (one-sided α = .05) is obtained by solving:

$$-t = \frac{y - \theta X}{(S_Y{}^2 + (\theta S_X)^2)^{\frac{1}{2}}}$$

$$E = (1 - \theta)\%$$

where t is the 95th percentile of a t-distribution with df = n - 1

(8) An upper confidence bound for E is obtained by solving:

$$+t = \frac{y - \theta X}{(S_Y{}^2 + (\theta S_X)^2)^{\frac{1}{2}}}$$

$$E = (1 - \theta)\%$$

Using the values found in Table 5 and solving for n, X, Y, S_x, S_y and Θ the following confidence bounds for the three catagories of injury are obtained.

<u>K + A</u>

$$-2.132 = \frac{147.1-(\Theta)225.93}{(98.21 + (\Theta)^2 395.21))^{\frac{1}{2}}}$$

Θ = .833

Lower confidence bound =

1 - .833 = .167 = 16.7%

$$\Theta \quad +2.132 = \frac{147.1 -(\Theta)225.93}{(98.21+(\Theta)^2 395.21))^{\frac{1}{2}}}$$

= .515

Upper confidence bound:

1 - .515 = .485 = 48.5%

K + A + B

$$-1.833 = \frac{715.5-(\theta)(978.0)}{(1449.32+(\theta)^2(2465.12))^{\frac{1}{2}}}$$

θ = .837

$$+1.833 = \frac{715.5-(\theta)(978.0)}{(1449.32+(\theta)^2(2465.12))^{\frac{1}{2}}}$$

θ = .639

Lower confidence bound:

1 - .837 = .163 = 16.3%

Upper confidence bound:

1 - .639 = .361 = 36.1%

K + A + B + C

$$-1.833 = \frac{3757.9 - (\theta)5098.5}{(6395.2 + (\theta)^2(14092.06))^{\frac{1}{2}}}$$

$$\theta = .781$$

$$+1.833 = \frac{3757.9-(\theta)5098.5}{(6395.2 + (\theta)^2(14092.06))^{\frac{1}{2}}}$$

$$\theta = .696$$

Lower confidence bound:

1 − .781 = .219 = 21.9%

Upper confidence bound:

1 − .696 = .304 = 30.4%

These procedures, summarized in Table 6, resulted in empirical confidence bounds for the effectiveness of FMVSS 202 <u>within</u> the 1972 Texas Driver Oriented Accident Tape.

TABLE 6

EFFECTIVENESS OF HEAD RESTRAINTS AND CONFIDENCE BOUNDS

Type of Injury	Effectiveness of Head Restraints (%)	Confidence Bounds* (%) Lower	Upper
K+A	34.9	16.7	49.5
K+A+B	27.2	16.3	36.1
Any Injury	26.3	21.9	30.4

* One-sided α = .05

4

COMPARISON OF REAR AND SIDE IMPACT INJURY RATE REDUCTIONS

4.1 Motivation and Overview

The purpose of the multi-dimensional contingency table analysis of rear impact collisions was to isolate that portion of the difference between pre and post standard injury rates which is, in fact, due to the standard. The purpose was accomplished by taking four important variables (age, sex, TAD Severity and vehicle weight) that affect injury rates and are confounded with the presence or absence of head restraints. By adjusting the marginals of the pre and post standard populations to be identical for these four variables, their biasing effect on pre versus post standard injury rates is removed.

A potential shortcoming of the multi-dimensional contingency table analysis is that it only removes the biases due to the specific control variables introduced in the analysis. It does not remove biases due to other variables or underreporting of accidents involving older cars, except to the extent that these biases are reflected by the distributions of age, sex, TAD and vehicle size (An Evaluation of FMVSS for Passenger Car Steering Assemblies, pp. 156-158). So it is possible that the

effectiveness estimates are still overstated, because only part of the biases have been removed. Indeed, Table 6 shows that the effectiveness estimates based on multi-dimensional contingency table analysis were only 1 or 2 percent lower than the simple injury reductions calculated from the raw data (Table 1). Whereas this does not, by itself, prove that the procedure overstates effectiveness, it would be desirable to check the results with another procedure that removes biases in a blanket fashion and, if anything, leads to understated effectiveness estimates.

A more drastic procedure for removing biases is to compare the injury reduction in rear impacts (pre vs. post-Standard raw data) to the analogous reduction in a control group of crashes unaffected by head restraints or any other safety improvements. It is hypothesized that any injury reduction observed in the control group is due to biases in the raw data (and that similar biases exist in the rear impact data). Therefore, the effectiveness of head restraints is equal to the amount that the injury reduction in rear impacts exceeds the analogous reduction in the control group (Ibid. pp. 158-164).

Side Impacts were selected to serve as the control group. Side impact injury rates would not be substantially affected by the installation of head restraints. Side impacts are less than perfect as a control group because they may have been affected by other safety improvements, especially side door beams, which were installed on some 1969-72 models. Thus,

the injury reduction observed for side impacts is not necessarily due only to biases. In other words, the excess of the rear impact injury reduction relative to side impacts may somewhat understate the true effect of head restraints.

4.2 Data Preparation

The side impacts were extracted from the 1972 Texas Driver-Oriented Accident tape by a procedure exactly analogous to the one for rear impacts (Section 3.1 and 3.2). In particular, the same look-up table (by make-model and model year) was used to determine if cars were equipped with head restraints. Model/year combinations whose head restraint installation was uncertain were excluded from the extract, just as was done with the rear impacts (See Appendix B).

The drivers involved in the side impacts were tabulated by injury severity and head restraint installation. Three dichotomies of injury severity were used (K+A, K+A+B, K+A+B+C). The three resultant simple two-way tabulations of side impacts are analogous to the data on rear impacts shown in Table 1.

4.3 Calculation of Effectiveness

Table 7 shows the counts of injured and uninjured drivers in rear impacts (recapitulated from Table 1) and side impacts. Below each table, the reduction of the injury rates is calculated. At the bottom, the reduction in rear impacts is calculated relative to the reduction in side impacts, yielding an

TABLE 7

PRE AND POST-STANDARD INJURY RATES FOR DRIVERS IN REAR IMPACTS

(a) Rear Impacts

K+A INJURIES

	K+A	ALL OTHERS	
Pre	95	26098	26193
Post	85	37367	37452
	180	63465	63645

K+A+B INJURIES

	K+A+B	ALL OTHERS	
Pre	411	25782	26193
Post	415	37037	37452
	826	62819	63645

ALL INJURIES

	K+A+B+C	ALL OTHERS	
Pre	2105	24088	26193
Post	2201	35251	37452
	4306	59339	63645

CALCULATION OF OBSERVED INJURY REDUCTION

1 - (85/37452)(95/26193) =

1 - (.0023)/(.0036) =

1 - .639 = 36.1% reduction for post-standard

1 - (415/37452)/(411/26193) =

1 - (.0111)/(.0157) =

1 - .707 = 29.3% reduction for post-standard

1 - (2201/37452)/(2105/26193) =

1 - (.0588)/(.0804) =

1 - .731 = 26.9% reduction for post-standard

(b) Side Impacts

K+A INJURIES

	K+A	ALL OTHERS	
Pre	928	60794	61722
Post	952	74384	75336
	1880	135178	137058

K+A+B INJURIES

	K+A+B	ALL OTHERS	
Pre	3094	58628	61722
Post	3205	72131	75336
	6299	130759	137058

ALL INJURIES

	K+A+B+C	ALL OTHERS	
Pre	5093	56629	61722
Post	5572	69764	75336
	10665	126393	137058

$$1 - (952/75336)/(928/61722) =$$

$$1 - (.0126)/(.0150) =$$

$$1 - .840 = 16\%$$

$$1 - (3205/75336)/(3094/61722) =$$

$$1 - (.0425)/(.0501) =$$

$$1 - .848 = 15.2\%$$

$$1 - (5572/75336)/(5093/61722) =$$

$$1 - (.0740)/(.0825) =$$

$$1 - .897 = 10.3\%$$

(c) <u>Effectiveness of Standard 202</u>

$$1 - \frac{(1 - .361)}{(1 - .16)} =$$

$$1 - \frac{(.639)}{(.840)} =$$

$1 - (.761) = 23.9\%$ Effectiveness of Head Restraints

$$1 - \frac{(1 - .293)}{(1 - .152)} =$$

$$1 - \frac{(.707)}{(.848)}$$

$1 - (.834) = 16.6\%$ Effectiveness of Head Restraints

$$1 - \frac{(1 - .269)}{(1 - .103)} =$$

$$1 - \frac{(.731)}{(.897)} =$$

$1 - (.815) = 18.5\%$ Effectiveness of Head Restraints

estimate for the effectiveness of head restraints.

For example, the K+A injury rate in rear impacts is 36.1% lower for post-Standard cars than for pre-Standard cars. In side impacts, it is 16% lower. The effectiveness of head restraints is estimated by

$$1 - \frac{1 - .361}{1 - .16} = 23.9\%$$

Similarly, the effectiveness of head restraints in preventing K, A or B injury is 17% and in preventing any injury is 18%.

The effectiveness estimates generated by this conservative procedure are 8-10 percent lower than the estimates based on the multi-dimensional contingency table analysis.

4.4 Derivation of Confidence Bounds

The preceding estimation technique involved taking the ratio of ratios of proportions of drivers injured and, in general, the samples were large. Thus, the Taylor series expansion gives a good approximation to the standard deviation of the estimates. Using these standard deviations, C. J. Kahane supplied formulas for nonsymmetric confidence bounds (one-sided $\alpha = .05$) which, although not rigorous, should be substantially more realistic than the symmetric confidence bounds based on 1.64 standard deviations.

The calculation of confidence bounds for each of the injury criteria follows. Table 8 summarizes the results. The effectiveness of head restraints in reducing overall injuries and K, A or B injuries is significantly greater than zero (α =.05) and the effectiveness for K or A injuries "comes close" to significance.

TABLE 8
EFFECTIVENESS OF HEAD RESTAINTS AND CONFIDENCE BOUNDS, BASED ON COMPARISON OF REAR AND SIDE IMPACT INJURY RATES

Type of Injury	Effectiveness of Head Restraints (%)	Confidence Bounds* (%) Lower	Upper
K or A	23.9	-0.2	40.7
K, A or B	16.6	5.5	25.8
Any injury	18.5	13.5	22.8

* One-sided α = .05

CONFIDENCE BOUNDS FOR K+A INJURY REDUCTION

n of injuries	95	85	928	952
N of cars	26193	37452	61722	75336
P of injury	3.627-03	2.270-03	.01504	.01264

$$\text{Effectiveness} = \varepsilon = 1 - R$$

$$\text{where } R = \frac{2.270\text{-}03}{3.627\text{-}03} \quad \frac{.01504}{.01264} = .7447$$

$$\varepsilon = 25.5\% = .2553$$

$$\text{Error} = S = \sqrt{\frac{1-.003627}{95} + \frac{1-.00227}{85} + \frac{1-.01504}{928} + \frac{1-.01264}{952}}$$

$$= .1560$$

$$= \frac{\varepsilon}{S} = \frac{.2553}{.1560} = 1.636$$

Since Z $<$ 1.645, effectiveness is not significant is greater than zero at α = .05, but since z $>$ 1.28, it is significant at α = .1

Lower confidence bound:

Solve $\frac{.7447-\theta}{\theta(.1560)} = -1.645 = \frac{R-\theta}{\theta S}$

$\varepsilon_\ell = 1 - \theta$

$\theta = 1.0017$

$\varepsilon_\ell = -0.2\%$

Upper confidence bound:

Solve $\frac{.7447-\theta}{\theta(.1560)} = +1.645 = \frac{R-\theta}{\theta S}$

$\varepsilon_u = 1-\theta$

$\theta = .5926$

$\varepsilon_u = 40.7\%$

CONFIDENCE BOUNDS FOR K+A+B INJURY REDUCTION

	REAR		SIDE	
	Pre	Post	Pre	Post
n of injuries	411	415	3094	3205
N of cases	26193	37452	61722	75336
p of injury	.01569	.01108	.05013	.04254

$$\text{Effectiveness} = \varepsilon = 1-R$$

$$\text{where } R = \frac{.01108}{.01569} \qquad \frac{.5013}{.04254} = .8313$$

$$\varepsilon = 16.8\% = .1679$$

$$\text{Error} = S = \sqrt{\frac{1-.01569}{411} + \frac{1-.01108}{415} + \frac{1-.05013}{3094} + \frac{1-.04254}{3205}}$$

$$= .07337$$

$$= \frac{\varepsilon}{s} = \frac{.1679}{.07337} = 2.29$$

Since Z $>$ 1.645, effectiveness is significantly greater than zero at $\alpha = .05$.

Lower confidence bound:

Solve $\dfrac{.8313 - \theta}{\theta\,(.07337)} = -1.645 = \dfrac{R-\theta}{\theta\,S}$

$$\varepsilon_\ell = 1-\theta$$

$$\theta = .9454$$

$$\varepsilon_\ell = 5.5\%$$

Upper confidence bound:

Solve $\dfrac{.8313- \theta}{\theta\,(.07337)} = +1.645 = \dfrac{R-\theta}{\theta\,S}$

$$\varepsilon_u = 1-\theta$$

$$\theta = .7418$$

$$\varepsilon_u = 25.8\%$$

CONFIDENCE BOUNDS FOR K+A+B+C INJURY REDUCTION

	REAR		SIDE	
	Pre	Post	Pre	Post
n of injuries	2105	2201	5,093	5,572
N of cases	26193	37452	61,722	75,336
p of injury	.080365	.058769	.082515	.073962

$$\text{Effectiveness} = \varepsilon = 1-R$$

$$\text{where } R = \frac{.58769}{.080365} \quad \frac{.082515}{.073962} = .81584$$

$$\varepsilon = 18.4\% = .18416$$

$$\text{Error} = S = \sqrt{\frac{1-.080365}{2.05} + \frac{1-.058769}{2201} + \frac{1-.082515}{5093} + \frac{1-.073962}{5572}}$$

$$= .034797$$

Is effectiveness significantly greater than zero?

$$\text{Let } Z = \frac{\varepsilon}{S} \quad \frac{.18416}{.034797} = 5.29$$

Since $Z > 1.645$, effectiveness is significantly greater than zero at $\alpha = .05$.

Lower confidence bound:

Solve $\frac{.81584-\theta}{\theta(.034797)} = -1.645 = \frac{R-\theta}{\theta S}$

$$\varepsilon_\ell = 1-\theta$$

$$\theta = .36537$$

$$\varepsilon_\ell = 13.5\%$$

Upper confidence bound:

Solve $\frac{.81584-\theta}{\theta(.034797)} = +1.645 = \frac{R-\theta}{\theta S}$

$$\varepsilon_u = 1-\theta$$

$$\theta = .77167$$

$$\varepsilon_u = 22.8\%$$